NOAA Technical Memorandum ERL SEC-92

DEPARTMENT OF COMMERCE
UNITED STATES OF AMERICA

A FURTHER COMPARISON OF ESTIMATED USAF 55 SWXS Ap AND Kp INDICES TO OFFICIAL POTSDAM INDICES

C. Borst

Space Environment Center
Boulder, Colorado
April 1999

noaa NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION / Environmental Research Laboratories

NOAA Technical Memorandum ERL SEC-92

A FURTHER COMPARISON OF ESTIMATED USAF 55 SWXS Ap AND Kp INDICES TO OFFICIAL POTSDAM INDICES

Carter Borst

Space Environment Center
Boulder, Colorado
April 1999

UNITED STATES DEPARTMENT OF COMMERCE

William M. Daley
Secretary

NATIONAL OCEANIC AND ATMOSPHERIC ADMINISTRATION

D. JAMES BAKER
Under Secretary for Oceans
and Atmosphere/Administrator

Environmental Research
Laboratories

James L. Rasmussen
Director

NOTICE

For sale by the National Technical Information Service, 5285 Port Royal Road
Springfield, VA 22061

A Further Comparison of Estimated USAF 55 SWXS Ap and Kp Indices to Official Potsdam Indices

CONTENTS iii

LIST OF FIGURES iv

LIST OF TABLES iv

INTRODUCTION 1

WORLD-WIDE MAGNETOMETER DATA COLLECTION SITES 4

Kp AND Ap COMPUTATIONS 5

COMPARISONS BETWEEN USAF AND POTSDAM Kp VALUES 7

COMPARISONS BETWEEN USAF AND POTSDAM Ap VALUES 13

SUMMARY 21

ACKNOWLEDGEMENTS 22

REFERENCES 22

List of Figures

Figure 1. A map of the 55 SWXS magnetometer network, 1998.

Figure 2. A map of the Potsdam magnetometer network, 1998.

Figure 3. Potsdam and 55 SWXS Kp distribution for 1994-1995 and 1996-1997, classified by activity level.

Figure 4. Percentages of 55 SWXS 3-hourly Kp hits, overestimates, and underestimates by year and activity level.

Figure 5. Percentages of 55 SWXS 3-hourly Kp hits, underestimates, and overestimates for 1994 sectioned by UT time block.

Figure 6. Percentages of 55 SWXS 3-hourly Kp hits, underestimates, and overestimates for 1996 sectioned by UT time block.

Figure 7. Monthly and smoothed values of Ap (estimated) through geomagnetic minimum in 1997.

Figure 8. Potsdam Ap time series and Potsdam-55 SWXS difference bars for 1994.

Figure 9. Potsdam Ap time series and Potsdam-55 SWXS difference bars for 1997.

Figure 10. Percentages of 55 SWXS hits, overestimates, and underestimates for all years and activity levels.

Figure 11. Potsdam and 55 SWXS scatterplot (daily Ap for 1994-1997).

List of Tables

Table 1. Magnetometer stations used in calculating 55 SWXS and Potsdam Kp and Ap

Table 2. Converting station magnetometer deviations into K values.

Table 3. Converting 3-hour Kp indices into an Ap index.

Table 4. Observed categories for Kp and Ap indices.

Table 5. The 55 SWXS 3-hourly Kp performance for 1994-1997.

Table 6. Potsdam and USAF 55 SWXS Ap frequencies.

Table 7. The 55 SWXS Ap performance by activity category.

Table 8. The 55 SWXS Ap performance statistics.

A Further Comparison of Estimated USAF 55 SWXS Indices to Official Potsdam Ap and Kp Indices

ABSTRACT

The estimated USAF 55 SWXS Kp is a reasonably good approximation of the official Potsdam Kp. The USAF Kp estimation scored an overall 54.6% hit percentage while the USAF Ap estimation scored an overall 72.1%. In general terms, the estimates performed poorly in the extreme low and extreme high geomagnetic activity levels. Additional studies and increased observation sites are recommended to improve the estimation overall and with respect to the levels of activity.

1. INTRODUCTION

The U.S. Air Force (USAF) 55th Space Weather Squadron (55 SWXS) and the National Oceanic and Atmospheric Administration (NOAA) Space Weather Operations (SWO) work together to provide solar and space environmental data and forecasts to the world community with interests and resources in space. The 55 SWXS is a component of the 50th Space Wing (50 SW) located at Schriever Air Force Base in Colorado Springs, Colorado, and is the only operational space environmental squadron of the Department of Defense (DoD). SWO is a division within the Space Environment Center (SEC) located in Boulder, Colorado, and is the official and worldwide center for all other real-time solar and space environmental forecasting and data dissemination.

Geomagnetic field variations, especially magnetic storms and substorms, are of primary interest to the DoD and Air Force Space Command (AFSPC) because they have an impact on surveillance operations and communications, and hamper the readiness of U.S. Armed Forces. Several models and techniques have been developed by the Air Force to estimate near-realtime values of geomagnetic indices, Kp and Ap. These indices describe the average variation in Earth's magnetic field using a global chain of reporting stations. By knowing the state of the geomagnetic field as close as possible to realtime, the Air Force can mitigate the threat that space weather perturbations pose to resources and operations that rely heavily on satellites.

The 55 SWXS creates and issues estimated Kp and Ap indices and associated operational products every hour. These "p" indices, indicating *planetary*, attempt to summarize average geomagnetic variations occurring around the world. Kp is a 3-hourly index of geomagnetic activity, and Ap is the daily index, composed of eight 3-hourly Kp values. The official values of Kp and Ap are determined some weeks after the actual activity through a series of algorithms by GeoForschungsZentrum, in Potsdam, Germany (formerly in Göttingen, Germany). The USAF began issuing these products in June 1992. The first analysis comparing estimated Kp and Ap indices with the official values was published by Gehred et al. (1995). Their study included data from June 1992 until June 1994, and this study continues their work, expanding the data set from 1 January 1994 until 31 December 1997.

The Potsdam data set was acquired from the archives stored in the National Geophysical Data Center (NGDC) located in Boulder, Colorado. The daily and 3-hourly values of Ap and Kp were compared with the USAF 55 SWXS estimates. Both data sets were loaded into a spreadsheet program, and checked for missing values and bad data points before calculations were initiated. In the first portion of the data sets, the solar cycle is just beginning its decline from maximum, and enhanced geomagnetic activity occurs with higher frequency than average during this period. The last half of the data set, where the solar cycle is passing through minimum, shows a much higher frequency of low levels of activity. Computations were performed on the data to show the statistical correlations, time series analysis, and individual data point comparisons between the data sets. Graphs and tables were built, and appear later in this document, to illustrate the changes in frequency of geomagnetic activity levels and an overall shift of geomagnetic activity based on the current phase of the solar cycle.

In general, there is a visible improvement in the accuracy and correlation (R^2) between the previous study (Gehred et al., 1995) and this one. The statistical calculations show an R^2 of 0.921 between the Potsdam and USAF daily Ap values during the years 1994-1997 compared with an R^2 of 0.910 for years 1992-1994. A hit, for either Kp or Ap, is defined as when "both data sets have an equivalent value during the same time period, based on predetermined conditions," and is discussed in sections 4 and 5 for Kp and Ap, respectively. Overall hit percentages for Kp values have increased from the previous study's value of 51.6% to 54.6%. The Kp overestimates have risen 0.2% to 26.6% and underestimates have dropped 3.2% to 18.8% overall. The Ap hit percentages averaged 72.1% overall and increased continually by year from 66.0% in 1994, reaching a maximum of 82.2% in 1997. Overestimates for Ap tended to be much lower than underestimates in most years, but were nearly equal in 1997. Both of the USAF data sets, Ap and Kp, showed poorer performance during the solar minimum year, 1996.

2. WORLDWIDE MAGNETOMETER DATA COLLECTION SITES

The 55 SWXS produces its estimated real-time indices using data from a group of nine magnetometer stations. These stations are primarily located on North America between the latitudes of 40° and 65° N (35° to 62° N geomagnetic latitude) as shown in Figure 1. The Potsdam magnetometer sites are spread over a much larger region and include sites in the Southern Hemisphere (Figure 2). The latitudes, longitudes, geomagnetic latitudes, and other important information on these stations can be seen in Table 1. Stations between 60° and 80° N or S geomagnetic latitude are considered to be auroral stations and require much larger geomagnetic variations to reach active or storm levels than those in the midlatitude, or subauroral (35° to 60° N or S geomagnetic latitude), regions.

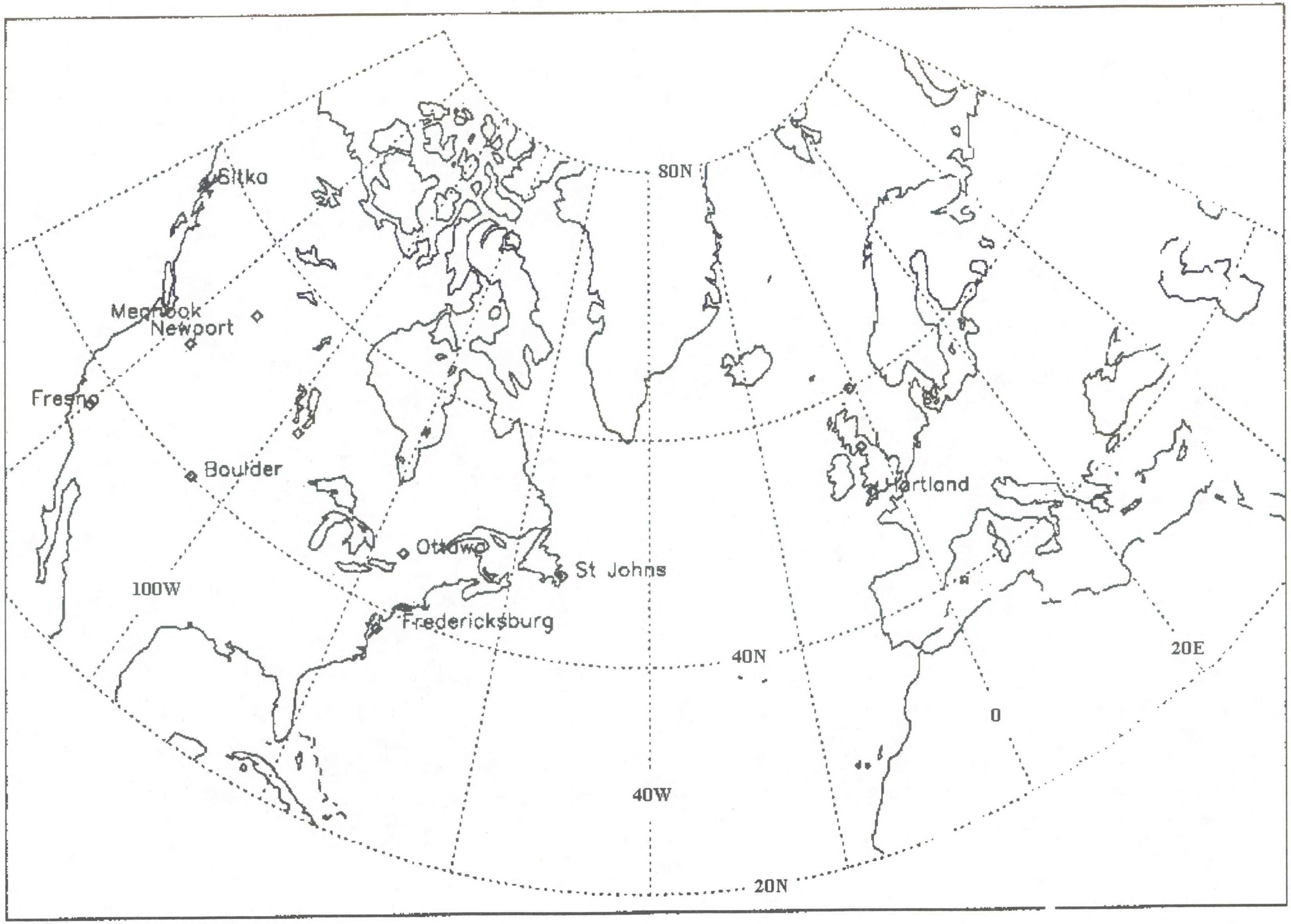


Figure 1. A map of the 55 SWXS Magnetometer Network, 1998.

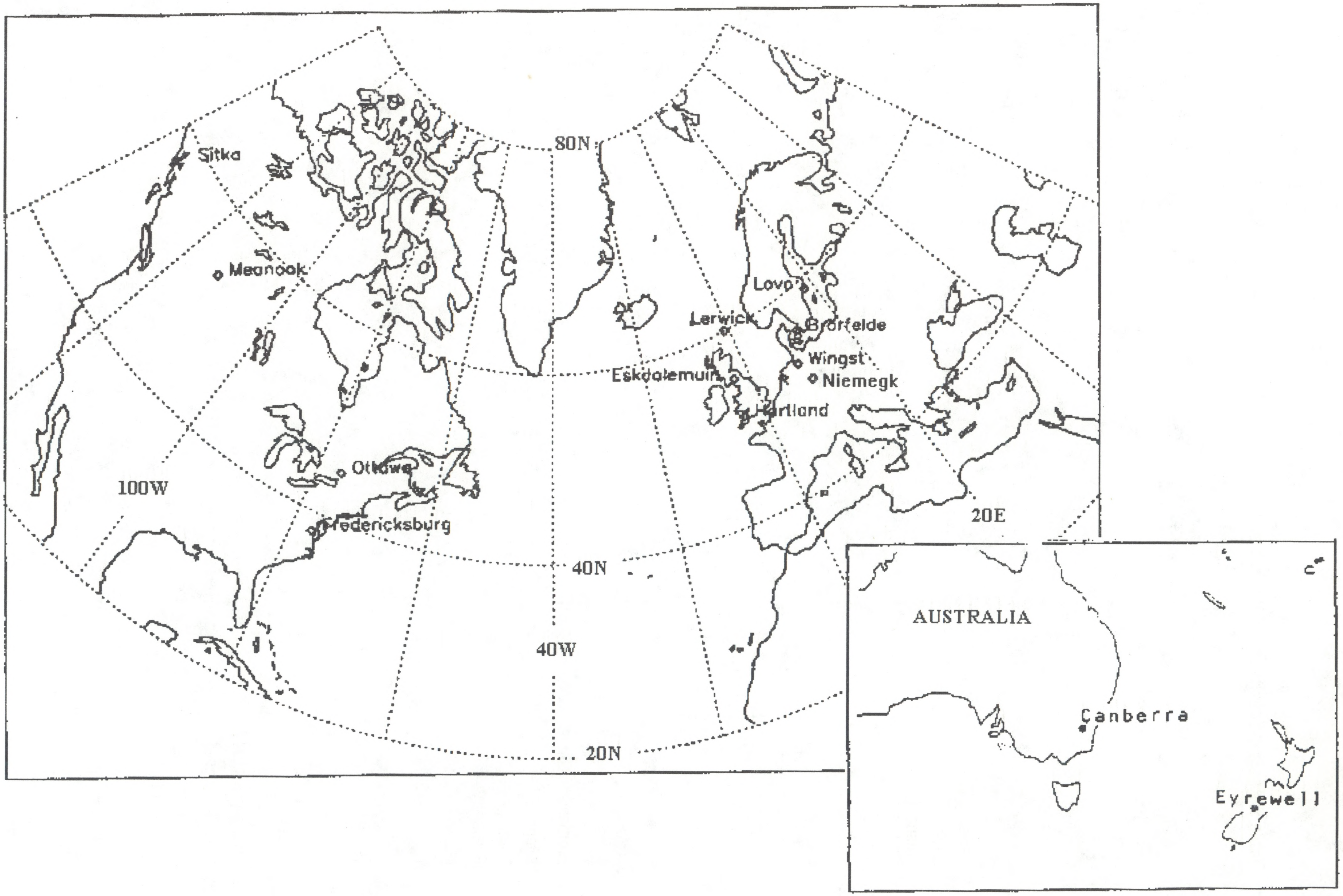


Figure 2. A map of the Potsdam Magnetometer Network, 1998.

Table 1. Magnetometer Stations Used in Calculating 55 SWXS and Potsdam Kp and Ap.

55 SWXS Kp/Ap

Station	Location (deg)	Geomag Latitude (deg)	Threshold of K9 (nT)	Code
Meanook, CN	N54 W113	N 62 *	1500	MEA
Sitka, AK	N57 W135	N 60 *	1000	SIT
Ottawa, CN	N45 W 76	N 57 *	750	OTT
Hartland, UK	N51 W 04	N 54 *	500	HAD
Fredericksburg, VA	N38 W 77	N 49 *	500	FRD
Saint Johns, CN	N47 W 52	N 58	750	STJ
Newport, WA	N48 W117	N 55	700	NPT
Boulder, CO	N40 W105	N 49	500	BOU
Fresno, CA	N37 W119	N 44	350	FSN

Potsdam Kp/Ap

Station	Location (deg)	Geomag Latitude (deg)	Threshold of K9 (nT)	Code
Meanook, CN	N54 W113	N 62 *	1500	MEA
Sitka, AK	N57 W135	N 60 *	1000	SIT
Ottawa, CN	N45 W 76	N 57 *	750	OTT
Hartland, UK	N51 W 04	N 54 *	500	HAD
Fredericksburg, VA	N38 W 77	N 49 *	500	FRD
Lerwick, UK	N60 W 01	N 62	1000	LER
Lovo, SWE	N59 E 18	N 58[1]	600	LOV
Eskdalemuir, SCOT	N55 W 03	N 58	750	ESK
Brorbelde, DEN	N56 E 12	N 53[1]	600	BJE
Wingst, GER	N54 E 09	N 54	500	WNG
Niemegk, GER	N52 E 13	N 52	500	NIE
Eyrewell, NZ	S43 E172	S 48[2]	500	EYR
Canberra, AUS	S35 E149	S 44[2]	450	CAN

* Used as stations for both networks.

[1,2] Stations are associated together and each used with a half weight.

(Provided by Dr. Hans-Joachim Linthe, GeoForschungsZentrum, Potsdam.)

Data used by the 55 SWXS are relayed in data blocks through Geostationary Operational Environmental Satellites (GOES) every 12 minutes. These data blocks consist of twelve 1-minute values of three magnetic components for each station. Antennae at Wallops Island, Virginia, receive the information via the GOES and relay the data to commercial Domestic Satellites (DOMSAT). The U.S. Geological Survey in Golden, Colorado, receives these data through a DOMSAT ground station and passes the data blocks to SEC via phone lines. At SEC, the data are unpacked, preprocessed, and routed to the 55 SWXS operations center.

3. Kp AND Ap COMPUTATIONS

The K index is a 3-hour quasi-logarithmic indicator of geomagnetic activity ranging from 0 to 9, 0 being very quiet and 9 being most disturbed. The K index is based on geomagnetic deviations from quiet day variations. Quiet day curves (QDCs) are the naturally occurring geomagnetic variations in the absence of perturbations from the solar wind structures. Because the QDCs can vary over time, they may influence the actual index measurement as well. The method of calculation used by Potsdam takes the current 3-hour geomagnetic deviations from the QDC in each horizontal component and records the range of these deviations as the amplitude of the activity during that period. The vertical component is not used because it is very sensitive to magnetic variations over great distances (Mayaud, 1990). The 3-hour maximum total range deviation is then converted to a K index as shown in Table 2. Potsdam standardizes the initial K values by doing additional conversions and adjustments to remove local time variations and other affects.

Each station has a K9 threshold value assigned to it, roughly derived from its geomagnetic latitude. K indices are calculated by stations all over the world, but are most appropriate at subauroral latitudes (Menvielle and Berthelier, 1991). K9 thresholds can range from as low as 250 nT at low geomagnetic latitudes to as high as 2500 nT at auroral geomagnetic latitudes. The conversion tables for the K index are determined as a fraction of the K9 threshold (See Table 2). In this way, the K index standardizes geomagnetic activity and minimizes differences due to variations in geomagnetic latitude. See Menvielle and Berthelier (1991) for a more detailed explanation.

Table 2. Converting Station Magnetometer Deviations into K values.

Fraction of K9		K		Fraction of K9	Example for Boulder, CO K9 Threshold = 500 nT
0	≤	0	<	0.01K9	< 5
0.01K9	≤	1	<	0.02K9	< 10
0.02K9	≤	2	<	0.04K9	< 20
0.04K9	≤	3	<	0.08K9	< 40
0.08K9	≤	4	<	0.14K9	< 70
0.14K9	≤	5	<	0.24K9	< 120
0.24K9	≤	6	<	0.40K9	< 200
0.40K9	≤	7	<	0.66K9	< 330
0.66K9	≤	8	<	K9	< 500
K9	≤	9			500+

An example of the K determination for Boulder, Colorado, is shown in Table 2 (Gehred et al., 1995). If the total range deviation were 31 for a given 3-hour period, the K would be 3.

The K values for all stations in the magnetometer chain during the 3-hour period are averaged to create the Kp value. The Kp index, scaled in 28 increments from 0Z, 0P, 1M, 1Z, 1P, … to 8P, 9M, and 9Z (where M is minus, Z is zero, and P is plus), is associated with a 3-hourly “equivalent amplitude” ap value, as shown in Table 3. The final step in converting all the previous measurements into the daily Ap value is to take the average of eight successive ap hourly "equivalent amplitude" ap value, as shown in Table 3. The final step in converting all the previous measurements into the daily Ap value is to take the average of eight successive ap values from 0000UT to 2400UT. For the study completed in 1995, the USAF initially calculated the ap values and converted them to estimated Kp values. These Kp values were then used to issue alerts and warnings of geomagnetic activity. Currently, both the USAF and International Association of Geomagnetism and Aeronomy (IAGA Potsdam) compute the K indices first, and then convert to ap and, finally, Ap values.

Table 3. Converting 3-hour Kp Indices into an Ap Index.

Kp	ap	Kp	ap
0 Z	0	5 M	39
0 P	2	5 Z	48
1 M	3	5 P	56
1 Z	4	6 M	67
1 P	5	6 Z	80
2 M	6	6 P	94
2 Z	7	7 M	111
2 P	9	7 Z	132
3 M	12	7 P	154
3 Z	15	8 M	179
3 P	18	8 Z	207
4 M	22	8 P	236
4 Z	27	9 M	300
4 P	32	9 Z	400

M, Z, and P stand for (M)inus, (Z)ero, and (P)lus, respectively.

For example, suppose we recorded the following series of Kp values:

Kp =>	3Z	4P	5Z	6P	8M	6M	4M	3Z
ap =>	15	32	48	94	179	67	22	15

In this case, the Ap value becomes $(\Sigma \text{ ap})/8 = 472 / 8$; hence the daily Ap index is 59. If there is any remainder left after the division operation, it is truncated to ensure an integer Ap value.

Table 4. Observed Categories for Kp and Ap Indices.

Category	Kp Range	Ap Range	To Hit Ap
Quiet	0 - 2	0 – 7	+/- 1
Unsettled	3	8 – 15	+/- 2
Active	4	16 – 29	+/- 3
Minor Storm	5	30 – 49	+/- 5
Major Storm	6	50 – 99	+/- 10
Severe Storm	7 - 9	> 100	+/- 20

Table 4 shows how the different indices are broken down into activity levels. The final column is discussed in section 5. The "to hit Ap" column indicates how close the USAF value needs to be to the Potsdam value in order for it to be considered a hit. The USAF Ap value may not be in the same activity category as the Potsdam value so long as it is within a given $^{+}/_{-}$ range.

4. COMPARISONS BETWEEN USAF ESTIMATED Kp AND POTSDAM Kp VALUES

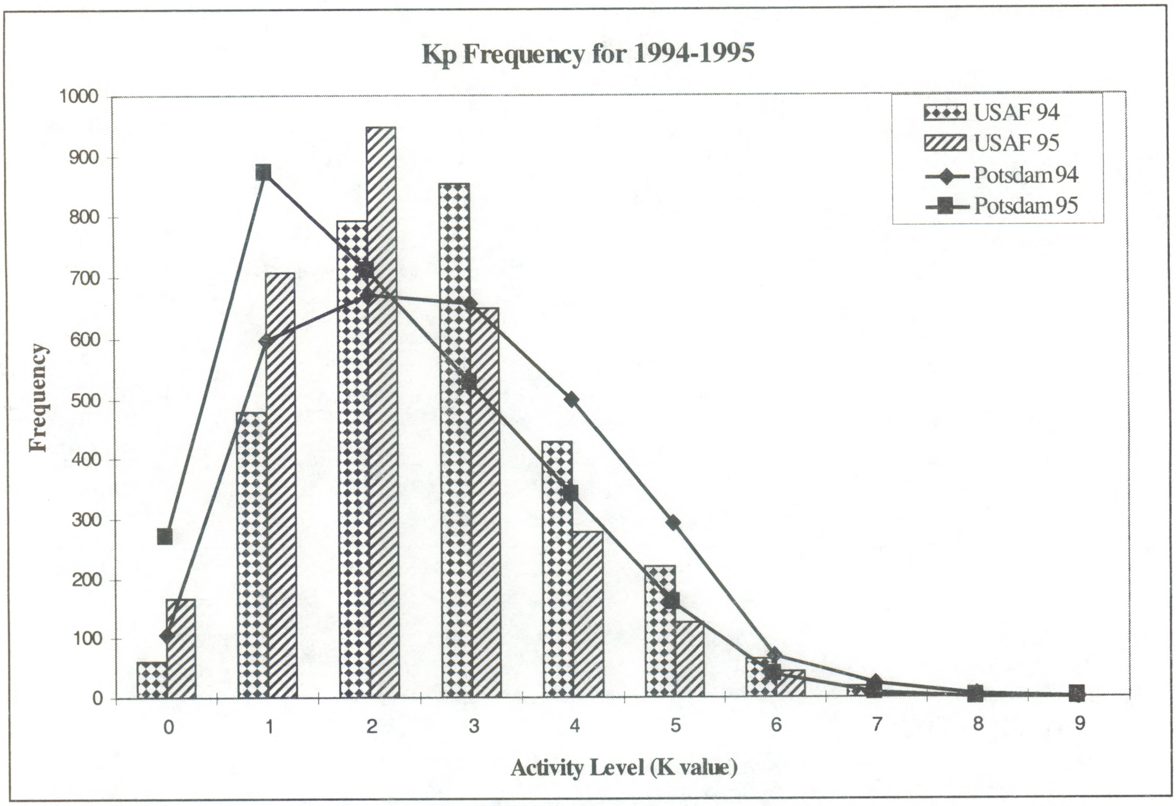
The comparison between USAF estimated Kp and Potsdam Kp is described in terms of hits, overestimates, and underestimates. A hit occurs when each data set has the same value at the same 3-hourly time interval. Overestimates occur when the USAF value is higher than the Potsdam value, and underestimates when the USAF value is lower. Table 5 shows the performance statistics for the 3-hourly Kp values for 1994-1997. For the total for all 4 years, over half of the values are hits, slightly over one-fourth are overestimates, and just under one-fifth are underestimates. Statistics on the occurrences of K values equaling 8 and 9 are not usable since the sample size is so small. The 55 SWXS Kp algorithm showed good success for Kp values of 1, 2, and 3. Overestimates for Kp values of 0, 1, and 2 showed a marked decrease from the previous report (Gehred et al., 1995). Underestimates showed very little improvement. For Kp values of 4, 5, 6, and 7, the underestimate percentages were higher than the percentages of hits. The lack of any underestimates for observed Potsdam Kp values of 0 occurs because it is not possible to underestimate the zero value of Kp.

Table 5. The 55 SWXS 3-Hourly Kp Performance for 1994-1997.

Kp	Potsdam	55 SWXS	Hits	Over-estimates	Under-estimates
Overall	11688	11688	54.6%	26.6%	18.8%
0	1084	832	47.3%	52.7%	- - - -
1	3563	2897	53.9%	37.4%	8.7%
2	3026	3676	61.0%	23.2%	15.8%
3	2077	2639	63.2%	13.5%	23.4%
4	1192	1018	40.9%	13.1%	46.0%
5	571	453	41.0%	9.3%	49.7%
6	129	138	43.4%	8.5%	48.1%
7	40	31	30.0%	2.5%	67.5%
8	6	3	16.7%	16.7%	66.7%
9	0	1	0.0%	100.0%	0.0%

Figure 3 reveals the distribution of Kp values by year for 1994-1995 (top) and 1996-1997 (bottom). Kp values drift toward decreased activity as the solar cycle passes into and through solar minimum. This trend is very evident in the bottom frame, and is shown by the top two counts in the graph being for years 1996 and 1997 in Kp activity levels of 2 and 1, respectively. Figures 4 shows a similar trend where the highest number of hits (top) and overestimates (middle) move to lower Kp values as the geomagnetic portion of the solar cycle proceeds to minimum (1997).

The data in Figure 4 (bottom) indicate that the number of underestimates are decreasing and moving toward lower activity levels as the data progress toward solar minimum. Because the activity is lower during minimum, the frequency of occurrences for lower K-index values



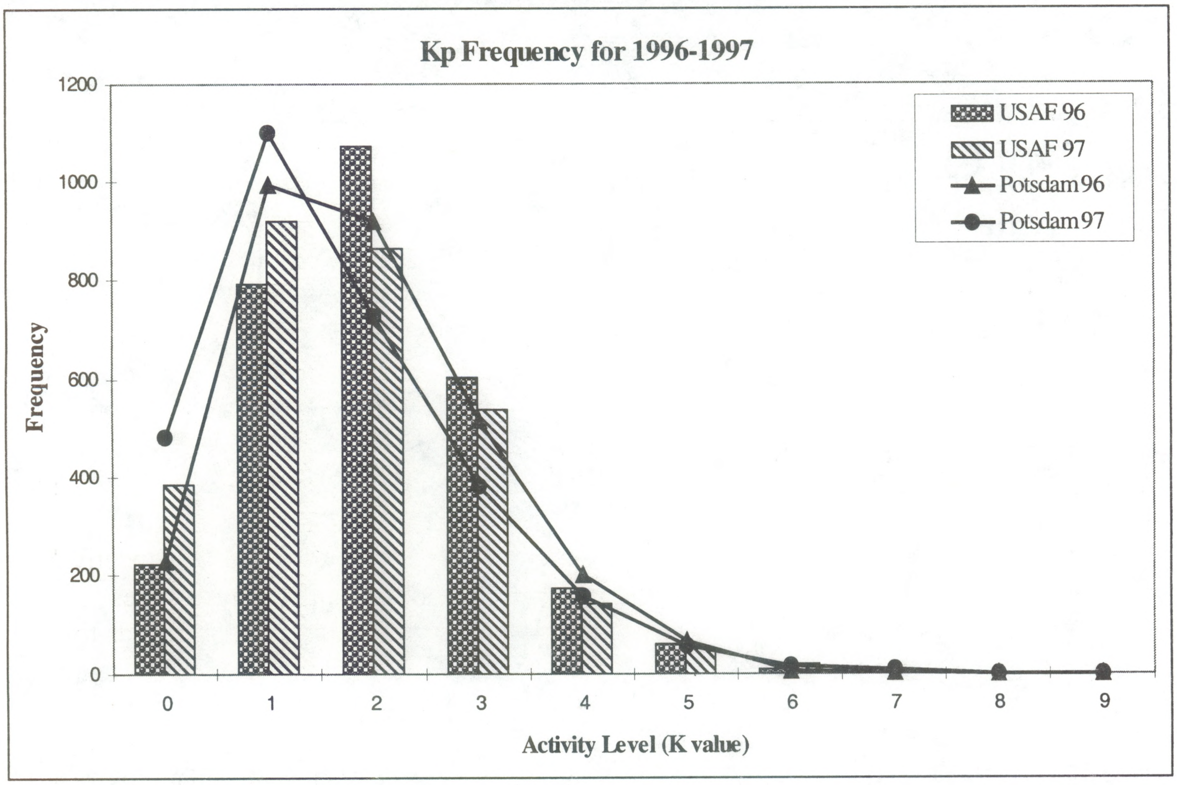


Figure 3. Potsdam and 55 SWXS Kp frequency for 1994-1995 (top) and 1996-1997 (bottom), classified by activity level.

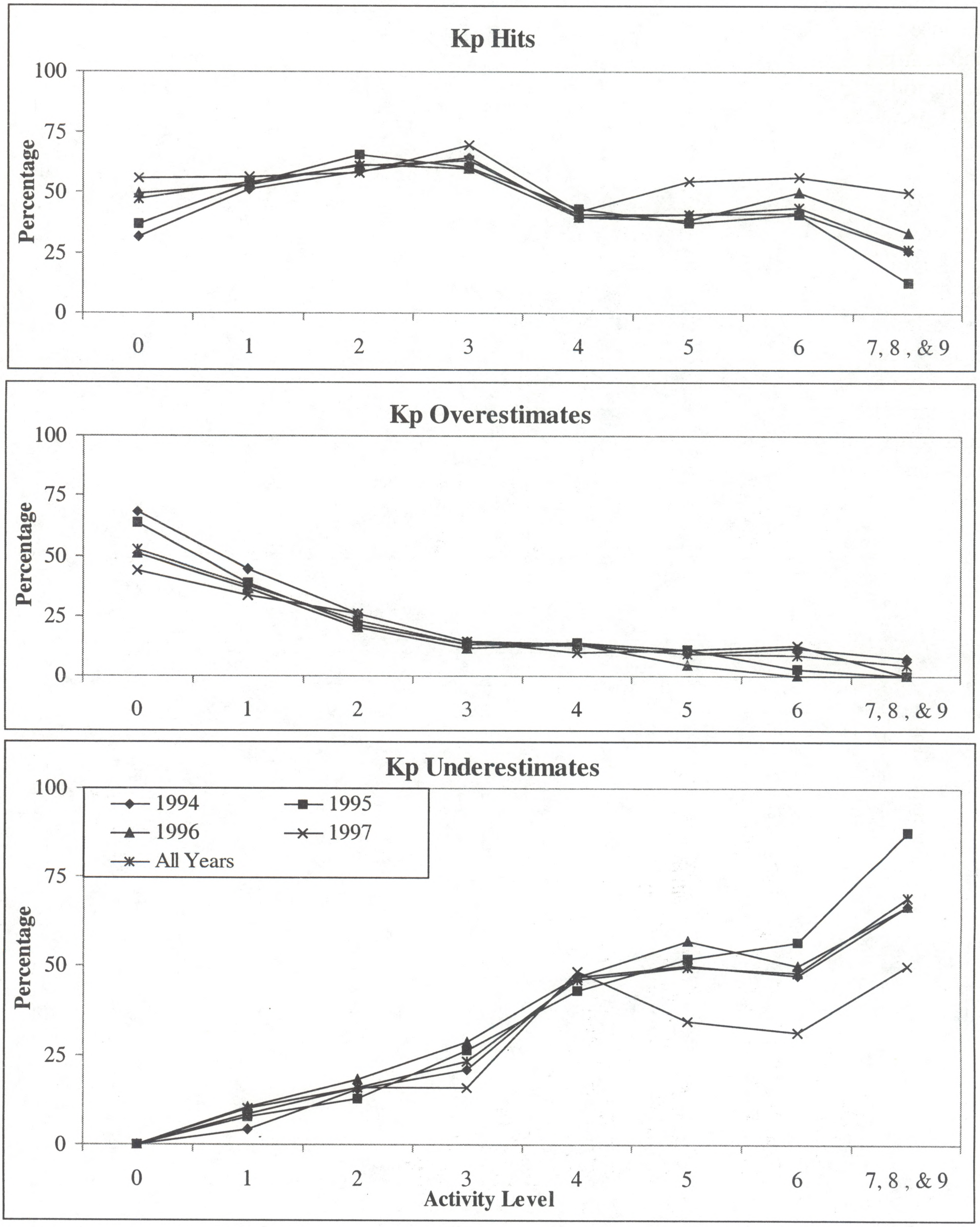


Figure 4. Percentages of 55 SWXS 3-hourly Kp hits, overestimates, and underestimates by year and activity level.

increases. Accordingly, fewer over- and underestimates will occur in storm-level activity because there will be diminished activity in these categories. Although the percentages of underestimates are high in the storming levels, there is a dramatic drop from 1994 to 1997. This is due to the low frequency of major and severe storms during solar minimum. There are at least 100 fewer underestimates in the active and minor storm activity levels in 1997 compared with 1994.

Figures 5 and 6 show the general pattern of hits, overestimates, and underestimates of the years 1994 and 1996, respectively, with data being grouped by 3-hour UT time block. Overestimates dominate from 0600 to 1200UT and underestimates dominate from 1800 to 2400UT in all years, some years showing domination more significantly than others. The suspected reason for this pattern is twofold. First, the stations that make up the two networks are geographically separated by as much as a 9-hour time difference. Second, the 55 SWXS network has only one station that is outside the continent of North America and no stations in the Southern Hemisphere. These conditions show the 55 SWXS network to be isolated enough to miss some substorms entirely. Gehred et al. (1995) discuss the seemingly regular pattern of over- and underestimation when data are broken down by UT time block. In the previous study, this effect was shown in the 0900 to 1500UT block for overestimates and 2100 to 0300UT for underestimates. The average longitudinal location of the non-common stations, those not providing data to both networks, were separated by approximately a 9-hour difference. During periods of overestimation, this would place the Potsdam non-common stations in 1200-2100 Local Time (LT) zone and the 55 SWXS non-common stations in the 0300-1200 LT zone. The resulting afternoon-evening/midnight-morning sector difference could give rise to the over- and underestimation patterns shown in past and current figures (Gehred et al., 1995). The point of

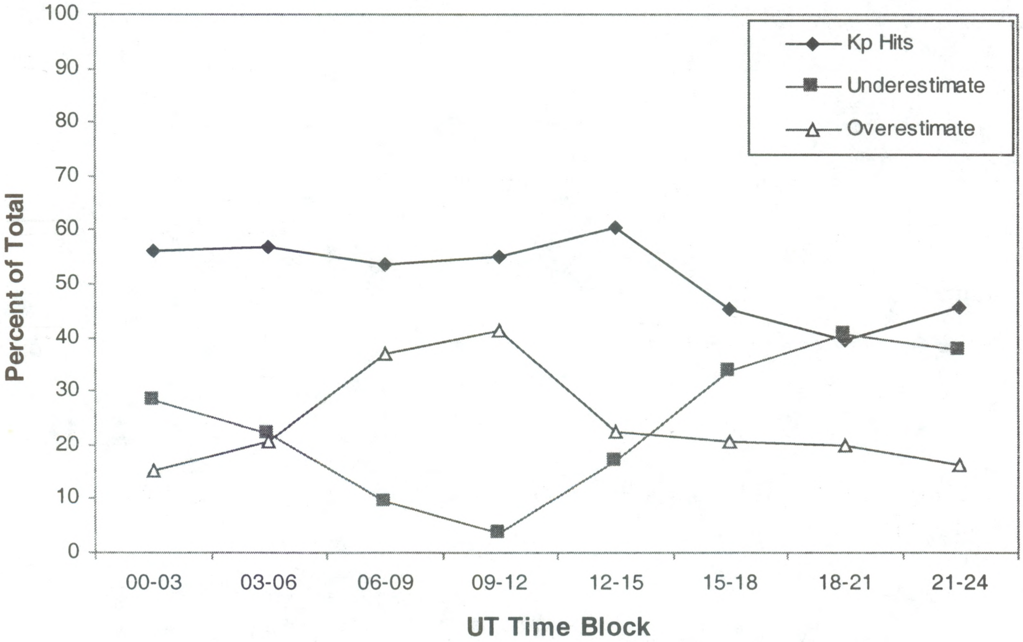


Figure 5. Percentages of 55 SWXS 3-hourly Kp hits, underestimates, and overestimates for 1994 sectioned by UT time block.

Gehred et al. about sector differences influencing the pattern of over- and underestimates still seems pertinent over a more extensive set of data and a longer period of time.

One possible explanation for these patterns of occurrence could be the missing of some sub-storms. Because of the localization of the non-common stations in each network (separated by an average of over 90°), sub-storms may affect one set of stations and not the other. Another possibility is that the QDCs are not adjusting properly during the transition from night to day or from day to night. In this case, the change in ionization due to gain or loss of direct sunlight may be affecting the measurements made during the early and late sunlit hours. This could cause the stations entering or leaving the sunlit sectors to over- or underestimate the indices for that day. These concerns and possibilities should be addressed outside of this report.

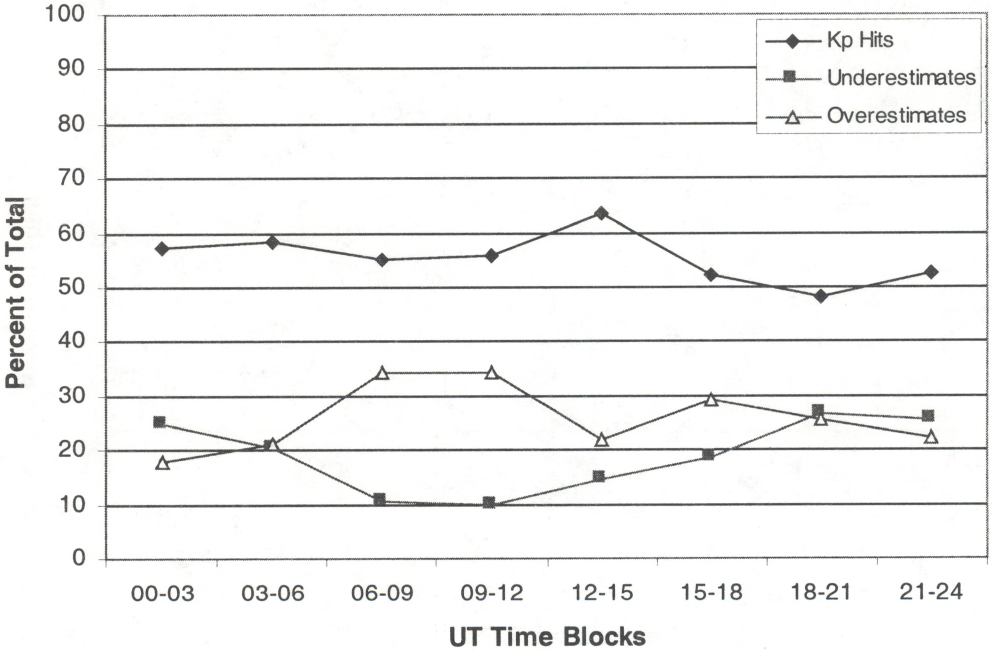


Figure 6. Percentages of 55 SWXS 3-hourly Kp hits, underestimates, and overestimates for 1996 sectioned by UT time block.

In the previous report (Gehred et al., 1995), 96 % of 55 SWXS Kp values were within $^{+}/$-1 of Potsdam's values whereas 97% of 55 SWXS Kp values met this criterion in the new data set from 1994-1997. With the number of stations common to both networks having increased by one (the addition of Hartland, UK), there is a slight increase in the hit percentage for the entire data set, 54.6 % compared with 51.6%. Overestimates increased by 0.2%, and underestimates dropped from 22.0% to 18.8% overall.

5. COMPARISONS BETWEEN USAF ESTIMATED Ap AND POTSDAM Ap VALUES

Comparisons between the Potsdam Ap and 55 SWXS estimated Ap values are based on a grouping by activity levels. Activity levels, Ap ranges, and corresponding Kp values are shown in Table 4. If the observed Potsdam Ap value falls into the quiet activity category, then the USAF Ap value must be within $^+/-$ 1 of the Potsdam value to be a "hit." The remaining activity categories follow this pattern. Active conditions allow values of $^+/-$ 3 around the Potsdam Ap to be hits while severe storm conditions can be as much as $^+/-$ 20 from the Potsdam value. Overestimates and underestimates are calculated in the same way as the Kp values, except USAF Ap values must fall above or below a range of "to hit" values for the observed Potsdam Ap values.

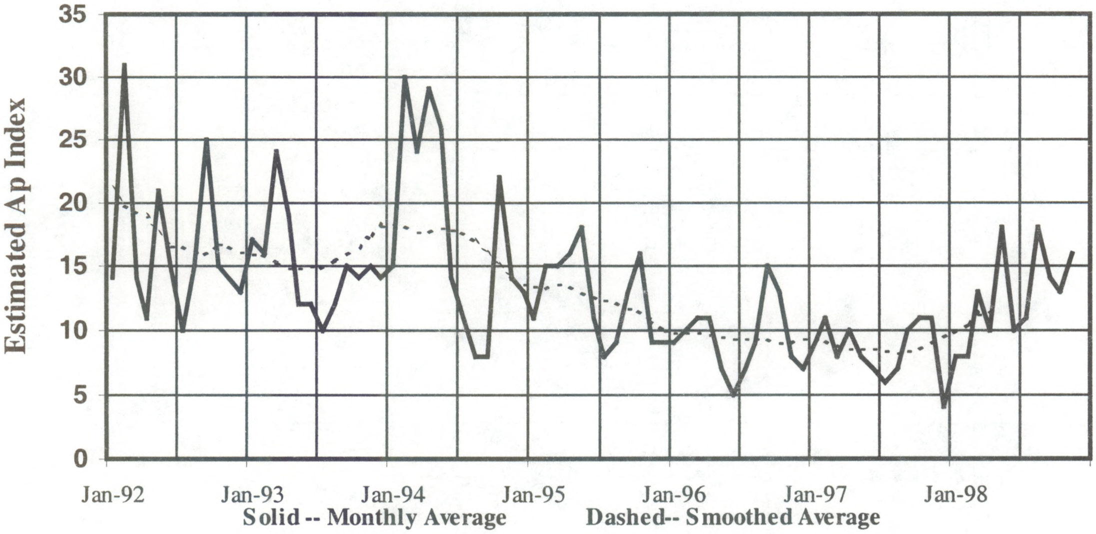


Figure 7. Monthly and smoothed values of Ap (estimated) through geomagnetic minimum in 1997.

Figure 7 shows the trend for values of estimated Ap over a portion of the solar cycle. The averaged daily values of Ap for a month are plotted in the chart (solid line). Smoothed monthly values are derived by averaging over 13 months with half weight being given to the first and last month (dotted line). This figure displays the large increase in activity during the latter portion of solar maximum (1989) and a slow decrease in activity until magnetic minimum is reached (1997). The decrease commences as smoothed values drop from well over 20 (active conditions) to less than 10 (quiet to unsettled conditions).

Figures 8 and 9 show a comparison of Ap values for 1994 and 1997, respectively. The Potsdam values are shown as the line graph, and the difference between Potsdam Ap and 55 SWXS Ap are shown in vertical bar format. From these graphs, a general decline in activity can be seen as well as the reduction of underestimation of Ap by 55 SWXS. This is highlighted by the decrease in difference lines appearing above the base line. The figures also show that the

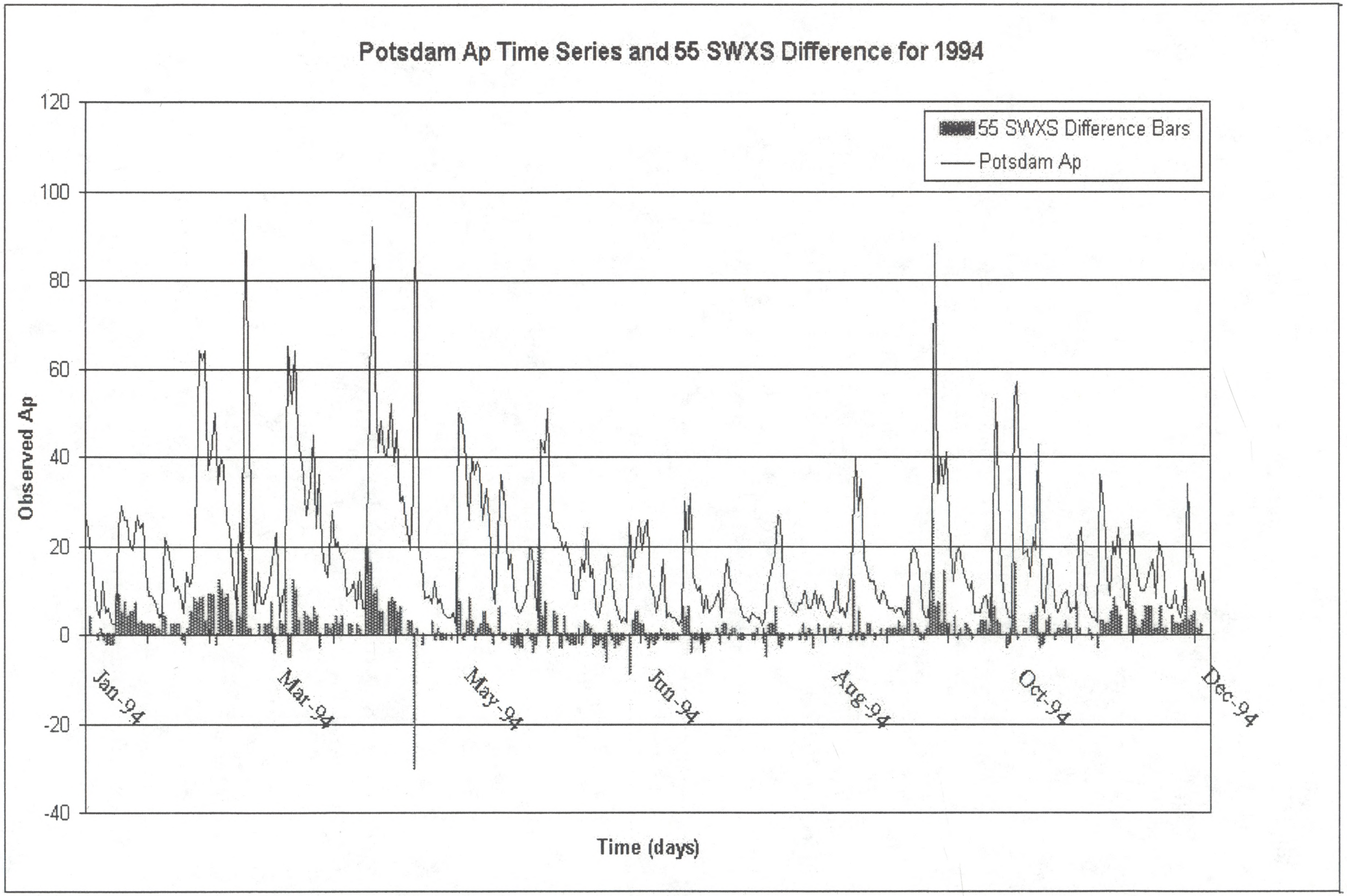


Figure 8. Potsdam Ap time series and Potsdam-55 SWXS difference bars for 1994.

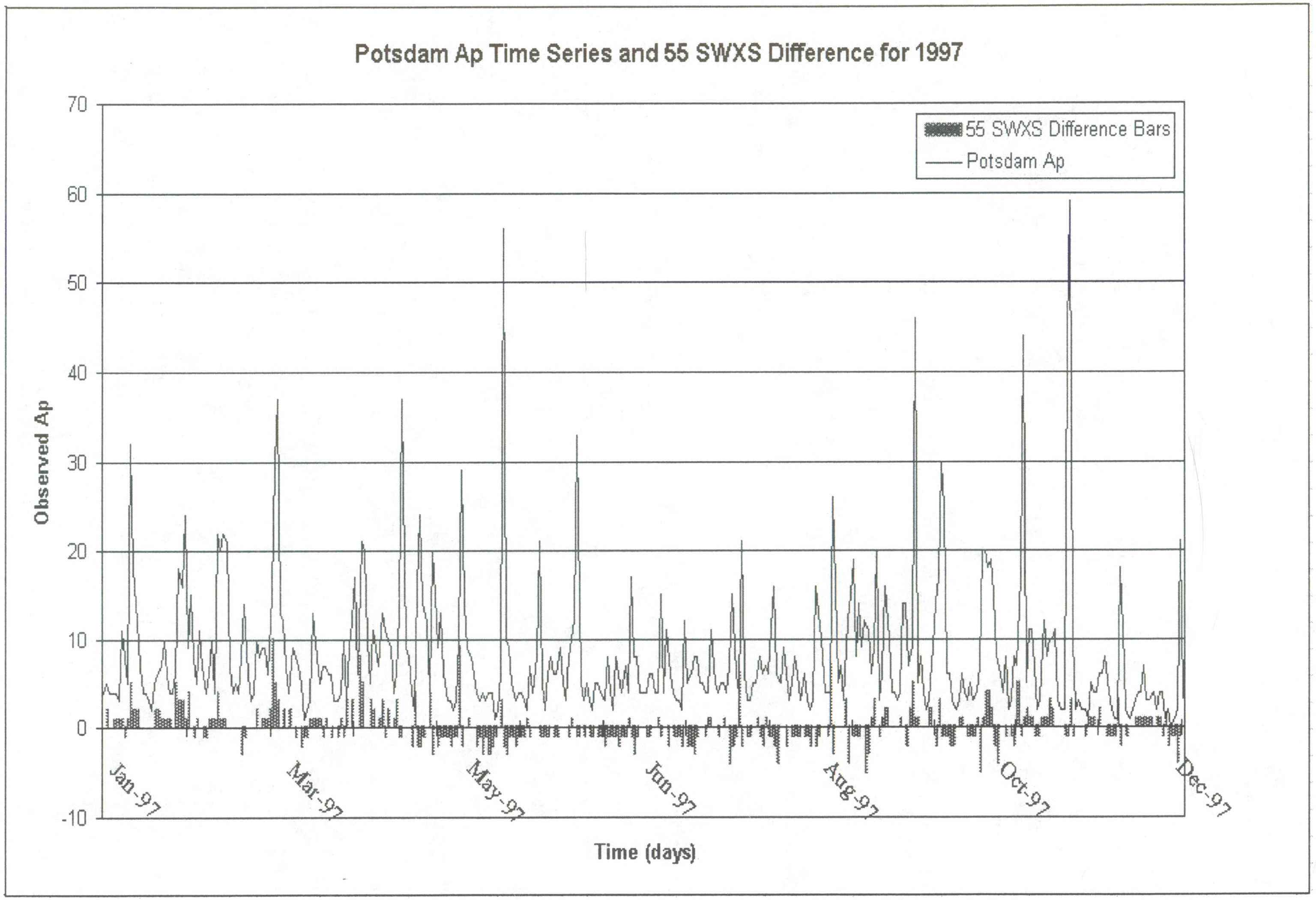


Figure 9. Potsdam Ap time series and Potsdam-55 SWXS difference bars for 1997.

magnitude of the differences decreases sharply from 1994 to 1997. Differences exceed 10 only once during all of 1997 whereas in 1994 this occurs over a dozen times, with a maximum difference of 35.

Table 6. Potsdam and USAF 55 SWXS Ap Frequencies.

	1994				1995			
	Potsdam		55 SWXS		Potsdam		55 SWXS	
	N	%	N	%	N	%	N	%
Quiet	109	29.9	116	31.8	171	46.8	175	47.9
Unsettled	100	27.4	106	29.0	85	23.3	94	25.8
Active	92	25.2	91	24.9	77	21.1	78	21.4
Min. Storm	44	12.1	41	11.2	30	8.2	16	4.4
Maj. Storm	19	5.2	10	2.7	1	0.3	2	0.5
Sev. Storm	1	0.3	1	0.3	1	0.3	0	0.0

	1996				1997			
	Potsdam		55 SWXS		Potsdam		55 SWXS	
	N	%	N	%	N	%	N	%
Quiet	190	51.9	203	55.5	222	60.8	223	61.1
Unsettled	128	35.0	123	33.6	98	26.8	103	28.2
Active	38	10.4	32	8.7	34	9.3	30	8.2
Min. Storm	10	2.7	8	2.2	9	2.5	7	1.9
Maj. Storm	0	0.0	0	0.0	2	0.5	2	0.5
Sev. Storm	0	0.0	0	0.0	0	0.0	0	0.0

	All Years			
	Potsdam		55 SWXS	
	N	%	N	%
Quiet	692	47.4	717	49.1
Unsettled	411	28.1	426	29.2
Active	241	16.5	231	15.8
Min. Storm	93	6.4	72	4.9
Maj. Storm	22	1.5	14	1.0
Sev. Storm	2	0.1	1	0.1

Table 6 shows the number and frequency of all Ap activity for each year of the data set and an overall compilation of daily Ap values. This table quantifies the story told by Figures 7, 8, and 9 as the percentage occurrence of quiet and unsettled activity rose from 57.3% in 1994 to 87.6% in 1997 for Potsdam. The USAF frequencies over the same periods were 60.8% and 89.3%, respectively. Figure 7 shows this trend over the length of several years, including the latter portion of the most recent solar maximum (1989) through solar minimum (1996). Less than 2% of the Ap values over the 4-year time (1994-1997) fall within the major or severe storm categories for either set of data.

Table 7 shows the performance of the daily Ap index overall and by year. The most noticeable aspect of the table is a continual increase in the overall hit percentage as the years progress, reaching a value of 82.2% in 1997. Because of the small sample size of activity at

Table 7. The 55 SWXS Ap Performance by Activity Category.

	1994				1995			
	Potsdam N	Hits	Over-estimates	Under-estimates	Potsdam N	Hits	Over-estimates	Under-estimates
Yearly	365	66.0%	8.5%	25.5%	365	69.3%	10.1%	22.5%
Quiet	109	78.9%	16.5%	4.6%	171	79.5%	14.6%	5.8%
Unsettled	100	73.0%	10.0%	17.0%	85	78.8%	9.4%	20.0%
Active	92	53.3%	2.2%	44.6%	77	49.4%	5.2%	45.5%
Minor S.	44	52.3%	0.0%	47.7%	30	36.7%	0.0%	63.3%
Major S.	19	52.6%	0.0%	47.4%	1	100.0%	0.0%	0.0%
Severe S.	1	0.0%	100.0%	0.0%	1	0.0%	0.0%	100.0%

	1996				1997			
	Potsdam N	Hits	Over-estimates	Under-estimates	Potsdam N	Hits	Over-estimates	Under-estimates
Yearly	366	71.0%	9.8%	19.1%	365	82.2%	9.6%	8.2%
Quiet	190	75.8%	12.1%	12.1%	222	85.6%	11.3%	3.2%
Unsettled	128	70.3%	7.8%	21.9%	98	82.7%	8.2%	9.2%
Active	38	52.6%	10.7%	39.5%	34	55.9%	5.9%	38.2%
Minor S.	10	60.0%	0.0%	40.0%	9	88.9%	0.0%	11.1%
Major S.	0	0.0%	0.0%	0.0%	2	100.0%	0.0%	0.0%
Severe S.	0	0.0%	0.0%	0.0%	0	0.0%	0.0%	0.0%

	All years			
	Potsdam N	Hits	Over-estimates	Under-estimates
Overall	1461	72.1%	9.5%	18.3%
Quiet	692	80.3%	13.2%	6.5%
Unsettled	411	75.7%	8.8%	15.6%
Active	241	52.3%	4.6%	43.2%
Minor S.	93	51.6%	0.0%	48.4%
Major S.	22	59.1%	0.0%	40.9%
Severe S.	2	0.0%	50.0%	50.0%

major or severe storm levels, any statistical observations made of Ap will be kept to categories of minor storm activity and lower. Underestimation was the primary error made in all years, with a peak of 25.5% in 1994. Most underestimation occurred in the active to minor storm categories.

Overestimation is unknown for minor storm conditions and is relatively small for all other categories of activity, excluding severe storm due to its small sample size. It is highest for quiet days with an average of 13.2%. Underestimation is small for quiet days (6.5% overall), but

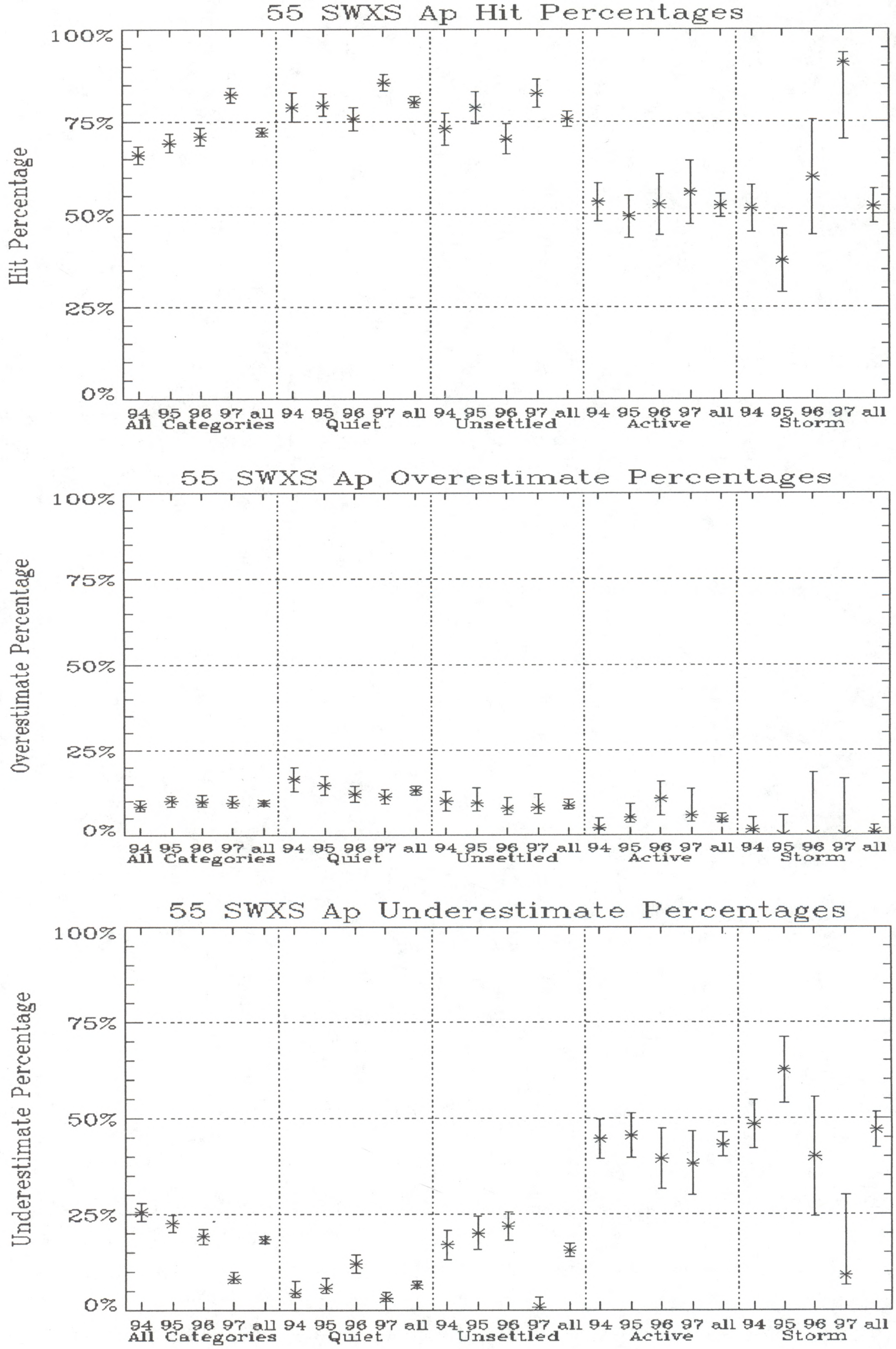


Figure 10. Percentages of 55 SWXS hits (top), overestimates (middle), and underestimates (bottom) for all years and activity levels.

increases steadily until it reaches minor storm levels (48.4%). During 1995, underestimates exceeded the number of hits for minor storm conditions. A large number of underestimates for active and minor storm conditions indicates a poor ability of the USAF algorithm to account for increased geophysical activity. The larger values of overestimation for quiet days also indicate that the algorithm does not handle them well. Overall, the algorithm seems to do well in the low to medium activity levels, but not well near the extreme activity levels.

Figure 10 illustrates well the percentages described in Table 7. The high percentages of hits for quiet to active conditions show an algorithm that is well suited to these types of conditions. The storm category contains all data from minor, major, and severe storms. These were combined to increase the number of data points to ensure usable statistics could be generated. As the geomagnetic activity moves to higher levels, the hit percentages decline gradually, the underestimate percentages increase, the overestimate percentages begin to decline, and error bar width increases. The trend of the data shows significant improvement as the period progresses, specifically in 1997. Storm statistics are somewhat erratic, as seen by the width of the error bars, but suggest improvements in this category as hit percentages increase and underestimates decrease continually after 1995.

Table 8. The 55 SWXS Ap Performance Statistics.

	1994	1995	1996	1997	All Years
Number of counts	365	365	366	365	1461
R squared	0.918	0.917	0.855	0.944	0.921
Bias, mean difference	2.0707	0.9102	0.5492	0.0493	0.9192
Standard deviation	13.56	9.38	6.33	7.4	10.13
Median	11	8	7	6	8
Maximum difference	35	26	16	10	35
Minimum difference	-30	-8	-20	-5	-30
For Potsdam Ap $\geq$ 30					N = 124
Mean difference	---	---	---	---	5.12
Standard deviation					13.31
For Potsdam Ap $\geq$ 50					N = 24
Mean difference	---	---	---	---	8.58
Standard deviation					17.92

Table 8 consists of regression statistics for each year individually and for the data set as a whole. The largest positive and negative differences, both occurring in 1994, were +35 and –30, respectively. The first and second quarters of 1994 were the last strong, geomagnetically active period of solar cycle 22 as shown in Figure 7. Table 8 also shows the number of larger geomagnetic storms that occurred during the data period. The number of storms within the category is listed above the mean difference of observed values.

Figure 11 shows a scatter plot of the daily Ap values for Potsdam and 55 SWXS. A linear regression trend line (dashed line) is included with the R^2 for all years. Table 8 shows a significant improvement in the R^2 for 1997 (0.944). The solid line in Figure 11 shows a perfect verification curve, i.e., when every observed value is the same for both sets of data, for comparison. The overall regression value for 1994-1997 is lower than in the previous study (0.96) (Gehred et al., 1995). Direct comparisons of estimated Ap values for 1994-1997 show an R^2 of 0.92, a very close approximation of the Potsdam Ap.

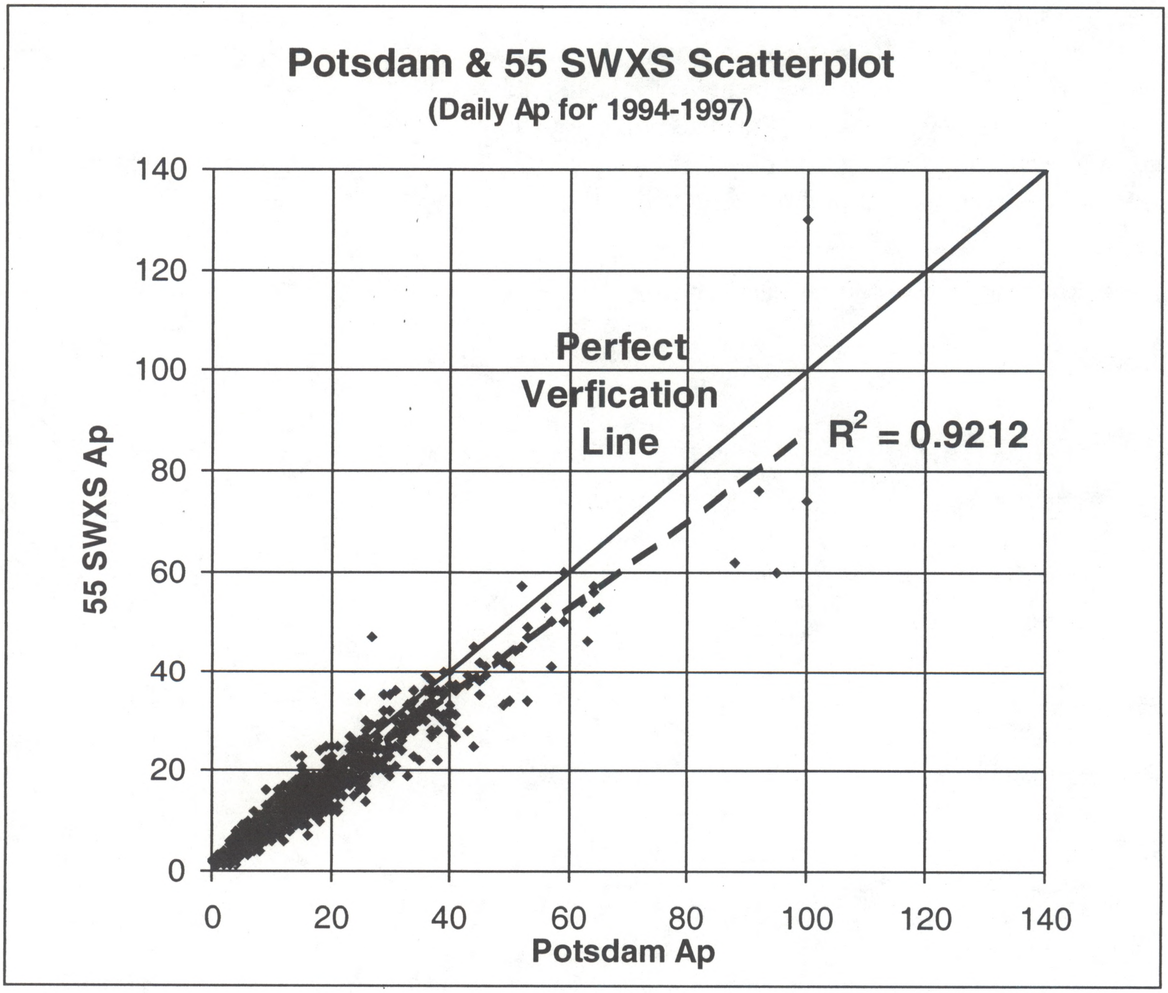


Figure 11. Potsdam and 55 SWXS scatterplot (daily Ap for 1994-1997).

Several data points in the major to severe storm categories ($Ap \geq 50$) deviate far from the "perfect value" line. The largest deviation was for a severe storm for which the Potsdam Ap value was 133 while the USAF value was 99. This disparity between these values could be caused by the positioning of the stations (tight versus well-distributed groups) or by actual storm mechanics that influence one portion of the Earth more than another (day-side versus night-side). Both of these possibilities could be solved by expanding the number or geographical location of the current network stations. An adjustment to the geographical distribution of the stations or a reevaluation of the joint network stations should be given some thought.

SUMMARY

The USAF 55 SWXS Kp performance improved marginally over the last 3 years as geomagnetic activity has declined. Overall, the hit percentage has increased 3.0%, overestimates have increased by 0.2%, and underestimates have decreased by 3.2%. Hits for quiet activity levels improved by 11%. Kp frequencies retained a similar distribution to those seen in the previous study (Gehred et al., 1995).

The USAF Ap performance showed significant improvement in this study as compared with the 1992-1994 study (Gehred et al., 1995). Overall, hit percentages were 72.1% for all years compared with approximately 61% for the earlier study. The highest percentage was for 1997, which reached 82.2% for hits over the whole year and 85.6% for quiet activity. Ap performance statistics show an improvement in the R^2 values for 1997 to 0.944, 0.031 higher than the 1994 data in the last study. Overestimates dropped slightly from the previous study, 12.8% for 1993-1994 vs. 9.5% for 1994-1997. Underestimates dropped sharply, from 25.8% overall for the last study to 18.3% overall for this study. In 1995, underestimates rose to an average 50.5% in the active and minor storm categories, a number greater than the "to hit" percentage. The overall decline appears to be the result of a large number of quiet periods that were estimated correctly and a smaller number of minor storms missed.

Future improvement of these statistics will have to be developed through an increased number of reporting stations and/or improved computer algorithms. Current interests and data requirements are pushing toward measurement of the D_{st} index (a geomagnetic index describing variations in the equatorial ring current) and gathering of ionospheric data for scintillation, radio wave propagation, and trans-ionospheric communication. From these studies, a better index or technique may be generated for use in future models.

As mentioned in the previous study, there should be a more in-depth study undertaken to understand the seemingly diurnal variations in the over- and under-estimates. Three possible starting points would be the influence of substorms on individual or tightly grouped stations, the latitudinal compactness of each of the magnetometer networks, or that the quiet day curves, change over time and their adjustments are not taken into account by some of the stations in the network.

7. ACKNOWLEDGMENTS

I would like to thank everyone who has helped me prepare for, critique, and finally accomplish this project. They are Paul Gehred, Joe Hirman, Dr. Hans-Joachim Linthe, and the SEC Editorial Review Committee. A special thanks to Chris Balch who helped make this project come out as well as it has by reading and rereading this material for me. Last, but not least, I thank my wife, Dariya.

8. REFERENCES

Gehred, P.A., W. Cliffswallow, and J.D. Schoeder III, *A Comparison of USAF Ap and Kp Indices to Göttingen Indices*. NOAA Tech. Memo. ERL SEL-88, NOAA Space Environment Laboratory, Boulder, Colo., 1995.

Menvielle, M., and A. Berthelier, The K-derived planetary indices: Description and availability, *Review of Geophysics*, vol. 29, no. 3, pp. 415-432, 1991.

Mayaud, P.N., *Derivation, Meaning, and Use of Geomagnetic Indices*, Geophysical Monograph 22, American Geophysical Union, Washington, D.C., 1990.

*U.S. GPO 1999-0-773-022/40137